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ABSTRACT

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A PRE-LAB GUIDE FOR GENERAL CHEMISTRY: IMPROVING STUDENT UNDERSTANDING OF CHEMICAL CONCEPTS AND PROCESSES

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Abstract

This study investigated perceptions of 56 students, in four general chemistry labs taught by two instructors, regarding their understanding of chemical concepts and processes. Conceptual understanding of scientific investigation was the focus. Students using a pre-lab guide for lab preparation were compared with students completing a traditional pre-lab assignment. Data sources included a student survey and interviews. Results were analyzed by common qualitative methods (Strauss and Corbin, 1990). Forty-one percent of students felt their pre-lab materials were helpful. Sixty-four percent expressed confidence in their ability to learn chemical concepts and processes; sixty-eight percent were confident of their ability to conduct chemical investigations. The experimental groups exhibited no significant differences. A significant instructor effect was found. Sixty-two percent of the students instructed by the researcher felt their approach was helpful; twenty-three percent of the adjunct's students were positive about their pre-lab tasks. Five themes emerged from the written student comments: aspects of the course, lab-related issues, instructors, assessment, and affective responses. Analysis of the interviews supported survey findings. Students using the pre-lab guide felt better prepared to conduct experiments and had a clearer understanding of chemical concepts and the scientific process.

Introduction

This study investigated the effects of a pre-lab guide for reading a college-level general chemistry lab manual and preparing to conduct the experiments on student understanding of the chemical concepts and of the experimental process of chemistry, and on the affective aspects of their experience in the general chemistry course.

Reforms of the chemistry curriculum and instruction at the college level have been proposed and argued for more than a decade (Bodner & Herron, 1980; Gillespie & Humphreys, 1980). General chemistry has been the focus of much of the effort to implement broad curricular change due to its key role in many programs of study (AAAS, 1990; American Chemical Society, 1990). Students' negative attitudes toward science and their flight from the science education pipeline to non-science majors are frequently attributed to their experiences in introductory chemistry courses (Rickard, 1992; Seymour, 1992; Tobias, 1990). Meadows and Koballa (1994) proposed that a two-stage process of retention is operative: success in general chemistry is the critical factor which must be accompanied by a positive attitude toward science for students to continue in science majors.

The American Chemical Society's Task Force on the General Chemistry Curriculum (Lloyd, 1994; Lloyd & Spencer, 1994; Spencer, 1994), recommended that changes in what is taught must be accompanied by changes in the way teachers and students interact, and in the way students interact with the subject. Particular emphasis must be placed on science as a method, not a collection of facts, and on the processes of investigation. Students must develop not only technical skills but thinking skills, and apply these to understanding chemical systems.

Further, the characteristics of the learners must be considered in revising the general chemistry course. The abilities, needs and goals of students now enrolled in, or soon to enter, college are different from those of their predecessors (Lloyd & Spencer, 1994; Tobias, 1990). Young adults in the information age have been disadvantaged in reading science text by the disassociation of science learning and print materials due to the emphasis on hands-on learning and inquiry activities (Holliday, Yore, & Alvermann, 1994). However, reading comprehension skills are particularly important for these students, who will need to learn new skills and information during their working life, often by reading independently without an instructor's guidance (Koch & Eckstein, 1995). The "bilingual character" of science text, which integrates both linguistic and mathematical/scientific symbols, and the necessity of learning a procedure in order to conduct the experiment further complicate the reading of a science lab manual (Alexander & Kulikowich, 1995).

Research has shown that students often fail to make connections between the concepts and processes underlying their chemistry lab experiments and the content of the lectures, perceiving two unrelated learning situations (Nakhleh, 1994). Students also often do not access their own prior knowledge and experience of chemistry in performing and learning from college lab experiments. Many students follow the procedure without understanding, as knowledge of chemistry is not perceived as necessary to perform the experiment (Blumenfeld & Meece, 1988; Nakhleh, 1994). In addition, students' understanding of the

chemical concepts and the process of scientific investigation from their pre-college experiences may be incomplete or inaccurate (Krajcik, 1991).

The science laboratory has been recognized as an effective setting in which to discern and modify students' understandings about chemical concepts and processes (Smith, 1991). Labwork can be used to foster conceptual change by presenting a problem that will involve students in scientific reasoning, by promoting explicit comparison of their existing ideas with the scientific viewpoint, and by supporting integration of their prior knowledge with their firsthand experience of the phenomenon.

The pre-laboratory guide employed in this study was intended to help students learn how to think about reading a lab manual and performing science investigations by directing their attention to the key elements of specific chemistry experiments. The pre-lab guide was designed to help students connect the lab content and process with both the lecture content and their prior knowledge of chemistry concepts and processes. The pre-lab guide also emphasized the process and structure of a scientific experiment, a major objective of the general chemistry reform effort. By teaching them to use this learning strategy, college students' ability to understand and apply the scientific method to science experiments in other instructional settings may also be enhanced. Such understanding is a vital outcome because this way of thinking about natural phenomena is the essence of science.

Methodology

Survey

The study was conducted during the fall semester of 1994 at a private women's liberal arts college in the Northeastern United States. A written survey was administered to students during the final pre-lab session. The survey instrument was designed by the researcher to measure students' perceptions of their use of the pre-lab guide or pre-lab assignment, and of their ability to learn chemical concepts and processes and to apply their knowledge and skills in the lab. The researcher based the instrument on a questionnaire derived from a student survey used by a chemistry department (Bennett, 1994). The pertinent questions embedded in the survey were intended to provide qualitative information concerning students' thoughts about their approach to preparing for lab and the process of investigating chemical systems, and their understanding of the chemical concepts and processes, as well as the affective outcomes of their general chemistry experience.

Three of the survey items directly addressed students' perceptions of their method of preparing for general chemistry lab, and students' confidence about learning chemistry concepts and processes, and about using their knowledge and skills in doing chemistry labwork. The data from these items were analyzed using a chi-square test to examine the relationship between the subjects' affective responses to their experience in the general chemistry course and their group assignment (Rea & Parker, 1992). Students' written comments on the survey were collected for each survey question and coded. These coded segments were organized into themes and categories emerging from the data that reflected students' perceptions of their experience in the general chemistry course and their understanding of the scientific process. An

experienced researcher checked and validated this procedure and the results.

Student Interviews

To obtain students' perspectives on their learning of chemical concepts and processes, and on the process of conducting a scientific investigation, qualitative interviews were conducted. Both students who used the pre-lab guide, and who used the pre-lab assignment, to prepare for chemistry lab were interviewed in formal, one-hour, semi-structured sessions. Students were also selected to include underrepresented ethnic groups and to reflect the demographics of the population. Sixteen percent of the class was African-American, seven percent were of Asian background, and four percent were Hispanic. Of the students interviewed, Elena was of Hispanic descendent, Manisha was of Asian heritage, and Shanel was African-American. The final sample consisted of eight students, two from each lab section. Table 1 gives the list of interview participants by pseudonym, major, group, and instructor.

Students were first interviewed about three weeks into the course, just after the use of the pre-lab guide was introduced, and again at the end of the intervention. The students were interviewed in the researcher's office during times convenient for the students, so that they were not rushed or under pressure. From the first interviews, the researcher identified additional questions, comments and insights, which were used in revising the protocol for the remaining students. Audio tapes were made of the interviews. All data from the student interviews were analyzed by accepted methods of qualitative analysis (Bogdan and Biklen, 1992; Miles and Huberman, 1994; Strauss and Corbin, 1990). The interview data were read and the investigator identified passages that were relevant to the study. These sections, ranging from a few words to a few sentences, were underlined and bracketed. The passages were then scanned and coded, using a system of abbreviations. The units of data were assigned coding category abbreviations which were tested and refined as the transcripts were read and reread. Units of data were multicoded when they fit more than one category. The interview data were then collected and organized by code into categories of student statements about their perceptions of and their affective responses to their experience in general chemistry. The passages were rescanned to winnow out any additional material of value. During the coding process, both confirming and disconfirming evidence were sought.

Subjects

The 56 subjects (all female, average age 18.6 years) were enrolled in the general chemistry course and lab designed for students in a science or science-related major, both lecture sections of which were taught by the investigator. Eighty-four percent of the students were freshmen, and seventy-five percent were residents on campus. While five percent of the students had no high school chemistry, seventy-three percent had taken one year and twenty-one percent had two years of chemistry in high school. About seventy-three percent of the students expressed an interest in majoring in science, with fifty-four percent in biology, seven percent in chemistry, eleven percent in engineering, and one student who indentified herself as a math/physics major. Sixteen

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percent were undecided and two students were majoring in elementary education and graphic arts.

All subjects were taking one of the four lab sections of the course. Each lab session consisted of a pre-lab/discussion period and a laboratory period, and lasted four hours, one day per week. The researcher and a lab instructor each implemented all instruction in two of the lab sections. The researcher's graduate training was in physical and inorganic chemistry, and she had taught the General Chemistry course for over 10 years at the time of this study. The lab instructor had a doctorate in inorganic chemistry and had previous teaching experience with both high school and college chemistry. She had taught the General Chemistry lab at this college for one year prior to this investigation.

Procedures

Explicit strategy instruction on use of the pre-lab guide was incorporated into the regular pre-laboratory instruction. The pre-lab guide was conceptualized as a "scientific story grammar" and consisted of eight questions about the purpose of the experiment, the chemical species to be studied, the variables involved and their relationships, the chemical method or technique used, the procedure and design of the experiment, and the hypothesized results. The effects of the pre-lab guide were compared with a traditional instructional approach in which students completed a pre-lab assignment to prepare for general chemistry lab. The pre-lab assignment consisted of problems and questions related to the calculations and procedure of the experiment.

For each of the eight experiments, the students read the lab manual and completed either the pre-lab guide or the pre-lab assignment prior to coming to their lab session. The instructors used the pre-lab guide as the basis for the pre-lab discussion with the treatment groups, and presented a traditional pre-lab lecture to students in the control groups. After conducting each experiment, students completed a written lab report. Some lab-based questions were included on pre-lab quizzes and tests.

Results and Discussion

The findings from the questionnaire are supported and illuminated by the results from the analysis of the student interviews. Together, they provide a window on students' understanding of the scientific process and their perceptions of their ability to learn chemical concepts and processes and to apply their knowledge and skills in the lab setting.

Survey Responses

Three questions on the student survey were of particular interest. The first item asked students to rate the helpfulness of the pre-lab guide/assignment they used to prepare for lab; the second and third dealt with their confidence in their ability to learn chemistry and in their ability to conduct chemistry experiments. Overall, forty-one percent of the subjects felt the pre-lab materials they used were helpful in preparing for lab. Sixty-four percent expressed confidence in their ability to learn chemical concepts and processes, while

sixty-seven percent were confident about investigating chemical problems. Analysis of the three questions showed that there was no significant difference between the experimental groups. The response of both groups to each of the three items was generally positive. The treatment group was slightly more negative, with fewer neutral responses, than the control on the first and third survey items, and slightly more positive, with fewer neutral responses, on the second question.

A significant instructor effect was found, with students in the researcher's lab sections being more positive on all three items, especially the first. In their rating of the helpfulness of the pre-lab guide/assignment, the lab instructor's students gave more negative than positive responses. On each of the three items, there was a consistent pattern for the negative responses; there were more negative than neutral responses for the lab instructor's students, compared to only one negative and several neutral responses on each for the researcher.

Comments on the Survey

Students were asked to provide written comments to explain their ratings of the survey items. Their notations on the survey centered around five themes: lab-related issues (pre-lab preparation, relative difficulty of labs), students' affective responses to the general chemistry course (confidence, motivation, self-regulation), concerns about assessment (synchronization of lecture and lab, lab reports), aspects of the course (pace, quality of lectures), and the instructors (lecturer, lab instructors). The pattern observed in the quantitative survey results was apparent in the written comments as well, with the researcher's groups tending to be more positive than the adjunct's sections in their responses.

Lab-related Issues. Lab-related issues were apparent in student comments on the first of the three survey items of interest. Overall, the survey results showed students felt the pre-lab task they completed to prepare for chemistry lab was helpful and that the students generally felt the lab sessions were fun. Student comments focused on the workload, and on the perceived helpfulness of the pre-lab task and of the pre-lab lectures in preparing for general chemistry lab.

The source of all but one comment about workload was a student in the lab instructor's groups, with most coming from students using the pre-lab guide. Most students complained that the pre-lab guide was "too time-consuming." Students in the two treatment groups offered different perspectives on the value of the pre-lab guide, suggesting an instructor effect. Compare this comment from the researcher's treatment group, "The pre-lab guide was quite tedious but it really helped prepare for and understand labs - I'd be lost without them!", to this remark from the lab instructor's treatment group, "The pre-lab guide was tedious and not worthwhile." One suggestion offered by a member of the same lab section to make the pre-lab guides more helpful was, "Write the pre-lab guide for each lab, to help us understand, otherwise they're useless!" Comments from students who completed the pre-lab assignments to prepare for lab came exclusively from the lab instructor's control group and were generally negative. The following remark offered some insight into students' perceptions of the value of this pre-lab task, "The pre-lab

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assignment was generally not helpful with lab (i.e., could do them without actually reading the labs)."

The second factor influencing students' experience of the general chemistry lab was the perceived difficulty of the lab experiments. Ratings of students' feelings about reading the general chemistry lab experiments gave some evidence of a group effect, in that the mean responses of the treatment groups were more positive than those of the corresponding control groups. One problem was the complexity of the lab separates, which was especially bothersome to students in the researcher's control group who had the lowest reading comprehension scores. One explained that the lab experiments written by the researcher were "more comprehendible [sic]", compared to the lab separates. A further area of concern was the occasional lack of coordination of the lecture and lab material. This issue seemed to be the root of many comments about the difficulty of the experiments, which came almost entirely from the lab instructor's control group. One student noted, "Instead of reinforcing principles, the labs are making chemistry more confusing." A related comment by a student in the researcher's treatment group shed some additional light on a problem students encountered in reading these experiments, "The lab separates are very difficult to follow, especially when the lecture hasn't covered the material."

Students' Affective Responses. Two items on the student survey addressed students' motivational beliefs (Pintrich and DeGroot, 1990). In this investigation, students' self-efficacy was defined in terms of their self-perception of their ability to learn chemistry concepts and processes and to apply their knowledge and skills in the chemistry lab. Several comments by the students were related to their motivational beliefs and expand on the quantitative findings from the two pertinent survey items. The comments also provided insights into students' self-regulated learning in the context of the general chemistry course.

While the students were generally confident, the researcher's sections tended to be more positive than the adjunct's students about their ability to learn chemical concepts and processes. This differential effect is seen in two comments from students using the pre-lab guide. One of the researcher's students wrote, "I like the course enough to believe I can do well (i.e., > C)", but a student in the adjunct's group illustrated her comment that her confidence in her ability to learn had "steadily dropped over the course of the semester" with an arrow pointing down. A student in the adjunct's control group explained, "I don't feel that I'm learning anything in lab. Most things I learned this year (99%) are from lectures alone." Regardless of group, for many students, their confidence level was higher than it had been in high school. A poor pre-college experience had soured their attitude toward chemistry, as this typical comment shows, "I'm terrified of chemistry and figured I'd fail for sure due to my poor high school performance." A similar pattern was found for students' confidence about doing chemistry labwork, with the researcher's groups being more positive about their ability. However, the only written comments came from two students in the adjunct's control group. One noted, "I'm always unsure", and the other related her trepidation to her fear of fire.

The survey questions about students' interest in and curiousity about chemistry are similar to items on Pintrich and DeGroot's survey (1990). Almost two-thirds of the general chemistry students expressed an interest in chemistry; a similar proportion said they were curious about chemistry. The adjunct's control group reported the greatest interest and curiousity, which may account for their good performance in general chemistry. One student in the researcher's control group explained that her lack of interest in chemistry had "nothing to do with this class." Further insight is provided by students' perception that doing the chemistry labs was fun. This evidently was a new experience for some, one of whom exclaimed, "I never liked labs!" Another revealed her fears about college chemistry by writing that she "found lab to be much better than I expected."

Some comments also revealed the differences in students' motivation to learn chemistry. The contrast is shown by the following remarks: "I want to have a better understanding of how/why phenomena happen as they do", and "Have quizzes after lab so the grade does not suffer." Other student comments were indicators of their use of cognitive strategies and self-regulation in studying general chemistry and preparing for lab. Some students made perceptive comments about their own learning in the general chemistry course. One noted that because of her strong high school chemistry background, "I tend to slack off and not do as well." Others expressed concern about their academic deficiencies. One said that her "prior chem concept knowledge was fuzzy;" another reported "a mental block on some types of calculations that has slowly dissolved this year." Another student described a common experience among college freshmen, who believe they know the material until faced with a test. Then, wrote one, "It seemed as though all I had studied didn't help or relate to questions on the test. I guess I had trouble applying what I learned in class." Another reported her response to this dilemma, "I've changed my study habits to raise my grade."

Assessment. Several survey items prompted student comments about the nature of the quiz and test questions, and the timing of the quizzes. Although students overall rated the quiz questions as appropriate, the groups which used the pre-lab guide were more positive than the control groups. Predictably, students felt the quizzes and tests were difficult, although the treatment groups rated the quizzes less so than the control groups, suggesting some advantage due to the pre-lab guide. Students in the control groups, especially the adjunct's group, commented most often about the difficulty of these tasks. Their comments showed that they found the pre-lab assignment of limited help in understanding the concepts and processes of the experiments. One of the researcher's control students wrote, "The pre-lab quizzes hurt me because I never completely understood, despite rereading the labs, until the teacher went over it." A member of the adjunct's control group agreed about the difficulty of taking "a quiz on a lab never done." For purposes of this study, the quizzes were designed to measure students' understanding of the concepts and processes related to the experiments after they had completed the pre-lab tasks. Unaware of the true intent of the quizzes, one student in the researcher's treatment group gave one remedy for the problem, "Go over the pre-lab guide before the quiz."

The tenor and sources of comments about the tests were similar. One remark from a student in the adjunct's control group revealed a

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common student expectation that test questions should be exactly like the lecture content, "Tests don't always reflect what was covered in class." Although the comments were critical of the timing of the quizzes in particular, and of the level of difficulty of the quizzes and tests, one student in the researcher's control group applauded, "During the tests and quizzes, students must think, not just simply 'regurgatate' [sic] information." Again, students made suggestions intended to improve their learning from the quizzes and tests, including the following insight from one of the adjunct's students, "We didn't go over homework problems in pre-lab, [which is] a problem when test time comes."

In this study, the lab reports served as one measure of student's ability to apply their knowledge and skills in the lab setting. On the survey, students rated the lab reports as somewhat difficult, with the researcher's groups being slightly more positive in their ratings. Most comments about the difficulty of the lab reports were made by students taught by the lab instructor. One student wrote, "The lab reports are the worst part, because I never understood the questions, even when they had been explained."

Aspects of the Course. Specific aspects of the course also led students to write comments. Among these were the textbook, the course lecture, and the pre-lab lecture. Almost 95% of the students thought the course lectures were understandable and clear, thus comments on this point were similar across groups. A student explained, "The teaching style makes it easy to understand." Added another, "[The researcher] explains things well in class. I like how she shows us things on the overhead and does experiments in class." Most comments about the pace of the lecture came from students in the adjunct's sections. There was disagreement, however, on this issue. One student reported, "Lecture well done, pace just right." Another complained, "I was bored to death, we moved so slow! Other people in the class never seemed to understand what was going on." Insight into the instructor effect is provided by two comments about the pre-lab lecture, which were made by students in the adjunct's control group. One wrote, "The pre-lab discussion was not helpful." The other reported, "The pre-lab lecture made me more confused - it seldom helped me with the experiment."

The Instructors. Although none of the survey questions directly asked students to rate the instructors, students nonetheless commented on the course instructor and on their lab instructor in the context of other items. The course instructor was perceived to be a positive factor by students, regardless of group. Said one student, "I'm passing due to a good teacher." However, student comments about the lab instructors were divergent and stemmed almost entirely from the adjunct's groups. From a member of the researcher's treatment group came this comment, "The instructor took the time to answer/discuss questions in pre-lab." Students in the adjunct's control groups revealed their frustration in comments like this, "I'm very disappointed in the lab instructor - she's not very good at explaining the lab or pre-lab." Another reiterated this point, "When we had questions, she did not have the answers." Although some students did not like having different instructors for lecture and lab, not all agreed, even if they were in the same lab section! Said one member of the adjunct's

sections, "I enjoyed having both [the researcher and the adjunct] as instructors." The adjunct's students identified possible sources of the difficulty. One explained, "The instructor couldn't answer questions because she didn't want to give away the answers to the quiz." Another recommended, "Improve communication between [the researcher and the adjunct] - students were not told what questions to skip on the lab reports." A third was blunt in her opinion, "Either the adjunct needs to prepare in a different way for labs or she should not be in charge of a lab section."

Student Interviews

Findings from the student interviews amplify and support the results from the questionnaire. The following vignettes provide each student's perspective on her experience in general chemistry, with particular regard to changes in her understanding of chemical concepts and processes. These snapshots are intended to help in deriving meaning from the students' perceptions, much as a story captures the richness of experience and the complexity of a person's understanding (Carter, 1993). The observations of Elena, Amber, Robin, and Nadine reflect the effects of the pre-lab guide on their learning. Shanel, Hannah, Lynda, and Manisha represent the experience of students in most college general chemistry courses, in which a traditional pre-lab assignment is used.

Elena. The pre-lab guide helped her to get "organized in a way", so that when she went to do the experiment, she already "had a clue" of what she was to do. Elena felt that she would be "lost" in lab if she had only read the procedure. If she didn't use the pre-lab guide, she would "just read it and even though I don't get it, I will say 'I read it'." By the end of the semester, the pre-lab question on the experimental procedure was no longer difficult, but, she reported, "I'm still getting stuck on the variable thing." However, after doing the experiment, "I can understand why this one's independent and the other one is dependent."

Elena's comments also revealed her attitudes toward science and her self-efficacy. "I've always liked science," she reported, but "it's tough....It's like an interest, so I do it." She liked doing the labs, especially since she had no previous chemistry lab experience. "Time passes so fast...It's exciting to see what happens, you know, the different reactions." She continued, "You're doing something fun at the same time you're learning."

She expressed her confidence in her ability to learn chemistry and to conduct chemistry experiments, saying, "I'm actually learning chemistry, how to deal with it, and how actually to go into a lab and do it!" Her performance reflected her incomplete understanding of chemical concepts and processes, however. "I think I understand it," she said, "but when it comes to the quiz and the test, I...just demonstrate that I've got a big mess in my mind!" Although she wanted a better grade, Elena remarked, "I don't feel bad because I'm actually learning it. I'm actually liking the class!"

Amber. Using the pre-lab guide was better than just reading the experiment prior to coming to lab, according to Amber, because "it makes you think about it more, what you're doing, and why you're doing it, and

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how you're doing it, and what you're doing it with." Using the pre-lab guide, Amber was confident of her ability to do the experiments, despite having no high school chemistry. Although she was "never quite sure what I'm supposed to be looking for, at least I recognize it when I see it!" In writing the lab report, she found the actual experience of doing the lab was more helpful than the pre-lab guide. Amber admitted that, given the choice, she would probably not use the pre-lab guide because "it takes a lot of time." She suggested modifying the task, advising "as we understand more and know more about what we're doing, ask for less."

Her attitude toward science also was evident in her comments. "I'm taking biology because I love it," she stated, "I'm taking chem because I have to." She went on, "Chem is a little harder, but...people said, 'You never took chem before. You're going to die!' I don't feel that bad!" Amber noted, "I know that I have to work at it harder."

Amber was satisfied with her performance, saying "I'm passing, I'm happy." Her understanding of the concepts and processes was another matter, however. She felt she understood things in class, but she said, "Then I go to take the test...I'll understand it until I have to use it." She identified a lack of study skills as one source of her difficulty, saying, "I know I'm going to do a lot worse if I don't learn how to study." Amber also found some of the lab-based questions on the pre-lab quizzes difficult because sometimes she "didn't fully understand the lab until we talked about it."

Robin. Robin responded positively about learning chemistry concepts and processes. She said, "I'm pretty much understanding everything" in class, and stating, "I kind of have an idea in my head of what's going on" about the chemistry labwork." Her confidence was tempered, though, by one concern about performing the experiment. She admitted, "I'm so afraid that I'm going to mess up everything!" Robin pointed out that she felt more confident working with a lab partner, especially when she didn't completely understand the experiment. Students took longer to do the experiment, she thought, "because we're afraid to do anything and we feel totally lost." She felt that the procedure question on the pre-lab guide had not helped her that much in lab, since she followed her lab manual so as not to miss any details. For her, writing out the procedure was "just in one ear and out the other. Get it on paper so...you can get on to something else!" Robin explained that the pre-lab guide was helpful at first, "until we were able to identify them things (sic)." However, she suggested that tailoring the task to each experiment would make it more beneficial by bringing out "certain points about the lab that you knew we wouldn't understand."

Her positive attitude toward science was an outgrowth of her parents' interest. She explained, "Science I've always liked and my parents have always liked." As to her major, she agreed with many of her classmates in general chemistry that "there's nothing else to go into but biology...or somewhere in the sciences." However, her career goals were changing, since she no longer expected "to go off to med school." Her expectations about her grade had also changed, since she would previously have greeted a high C with approval, but now it was "still not good enough."

Robin was positive in her evaluation of the general chemistry course and her performance, saying, "I hated high school chemistry!" She added, "I haven't failed yet, that says a lot!" One reason for her success in the course was that the researcher made "sure that we understand" during lecture. She thought college chemistry was "not as hard as I had expected it to be, because I'm actually understanding things as I go on."

Nadine. A transfer student from a community college, Nadine had a better math and science background than her freshman classmates. She felt the pre-lab guide was useful in understanding the chemical concepts and processes involved in the experiments, especially for the lab separates, which she found "harder to understand" than the department lab manual. Nadine said she had not felt the guide was that helpful at the beginning of the semester, because she saw it as "this long, drawn-out process. But I think it helps more now" in understanding the overall scientific process of the experiment. Without the guide, she would not be as well-prepared for lab, since she would not have "read it as thoroughly." She reported using the actual procedure in lab because she was concerned about leaving important information out of the pre-lab guide. However, she noted that the experiment was "easier to understand in my own words" as summarized in the pre-lab guide. "Writing the 'Why's!" and identifying the variables were the hardest parts of the pre-lab guide for Nadine. But she felt she was "picking up on things" in determining the independent and dependent variables. Nadine noted that the adjunct was "never sure of that herself!", thereby revealing a possible reason for the significant instructor effect found in the analysis of the survey results.

She professed, "I love science and math!" and thought her high school chemistry experience was very good. She commented that she sometimes felt confused in pre-lab and lab, explaining that because the adjunct "doesn't have us as a class, she has no idea where we are!" Nadine described the driving force for her desire to do well in general chemistry as "understanding the concepts," but added, "I like my grades to reflect what I understand."

The lab questions on the quizzes and tests were the hardest part of the course for her, "because I'm not used to having lab mixed in." She pointed out that the lab and the lecture complemented each other well at the end of the semester, although "in the beginning, in the middle, it was hard." Nadine was satisfied with her performance in the course, stating that her goal was "to be able to comprehend all of it and put it all together...and I think I've done pretty well at that so far."

Shanel. Shanel thought the pre-lab assignment was helpful in preparing for lab, and remembered how to solve some of the problems from her high school chemistry class. She felt she finally understood the concepts and processes after she had done the experiment "because, you know, I see it!...I can't just...read what's going on. I have to go through it for me to know it." As she read the lab, she tried to identify questions that might be on the quiz, and referred to previous quizzes as she studied. In lab, she usually felt prepared, but added there were times when she was confused and had to reread the procedure. The lab separates were "a little bit harder" to understand than the department lab manual. Shanel stated that she would prefer to do the

pre-lab assignment than just read the experiment and come to lab, because she felt better prepared. In describing how she prepared for lab, Shanel revealed that she often studied with Elena, and found talking about the pre-lab guide with her "very helpful." Thus, she used both the pre-lab assignment and the pre-lab guide in order to "get a good understanding" of the concepts and processes. In fact, she concluded, "a combination of the two" pre-lab tasks would be the most effective preparation for lab.

Her interest in science had been whetted by her experience in a summer science program for high school students. Shanel identified her mother as a "source of inspiration for me." She enjoyed doing the labs the most, explaining that "you are the person who's doing the experiment, getting the results...and you're kind of doing it on your own."

Although Shanel felt that she had "the potential", she was not satisfied with her performance in general chemistry and had decided that she had to "study harder" to improve her grade. She found the pace in college chemistry faster, saying everything that was covered in her high school chemistry class, "I learned in maybe one month in college". She added, "I learned a lot from the labs." She concluded, "In my heart, I think I really accomplished a lot."

Hannah. The pre-lab assignment, she felt, was "sometimes more difficult" than she expected after reading the experiment. However, she stated that she didn't always read the procedure completely, saying, "I don't need to read step 25 at this point, I don't understand steps 1 through 24!" She had more trouble with the lab separates, since "the steps seem sort of unclear, if nobody's really briefed you about the lab yet." She usually figured the procedure out in lab, because "it seems like it's easier...once you see the equipment, and once you're done steps 1 through 15." Hannah did not think that the pre-lab assignment prepared her for lab, but felt the pre-lab lecture was helpful. She noted, however, that without the pre-lab assignment, the lab questions on the "quizzes would seem sort of like what the pre-labs feel like now." For that reason, she would probably continue to do the pre-lab assignment, given the choice.

Her extensive high school science background included AP chemistry, so Hannah felt very confident about her ability to succeed in the general chemistry course and lab. However, she admitted she found the labs to be the hardest thing about college chemistry. She remembered concepts to some extent and enjoyed problem solving, but "when it comes down to doing it, it's kind of hazy." Hannah enjoyed the labwork, since it "was another way to understand what you're doing in class....it's a good application."

Assessing her performance in general chemistry, Hannah felt she was "doing OK." Nomenclature was the only difficult topic for her, but she felt she had "a better knowledge of that now." Hannah thought the lab questions on the pre-lab quizzes were difficult, especially if the experiment was complex conceptually and procedurally. She compared the density experiment, which involved "common knowledge", to the synthesis experiment with "mercury oxide and all this other stuff, you just can't figure it out." Her goal in general chemistry was "to actually learn chemistry this time. And I think I'm learning it more."

Manisha. Manisha attended high school in another country, under the British system. She found that the "theory part" of general chemistry was not difficult, but the lab was "really hard" because she was not familiar with the chemical equipment and basic lab techniques. She read the experiments to "just try to understand it." While she felt she knew the lab-related material on the pre-lab assignment, she did not think the pre-lab task prepared her for lab or the quizzes. She noted that it did help her understand why a certain technique was used and "what would happen if you didn't do something." Taking notes on the experiment was more helpful to her, since she found "if you write something down, it stays in your mind." Despite her efforts, however, sometimes she was "completely lost, and I have no idea what I'm supposed to be doing" in lab. It was only "when I sit and do the lab report", that she felt she understood the experiment.

Chemistry was "not one of my favorite subjects", she explained in discussing her desire to go to pharmacy school, "because it's hard for me." On the other hand, physics "makes so much sense to me...it's so logical."

Manisha found the lab questions on the quizzes difficult; "it was just fate," she said about her good performance on one quiz. She found that the more unfamiliar the concept or the lab procedure, the less she understood. However, she said of her experience in general chemistry, "So far, it's not so bad." Manisha expected chemistry "to be hard and it's not really hard."

Lynda. As she read the experiment, Lynda highlighted important information, after which she did the pre-lab assignment. If she had questions about the experiment, she asked a student who used the pre-lab guide, "because they do the longer procedure with 'What' and 'Why'." She found the general chemistry labs difficult because "it's applied to like what we're learning in class, that's totally different" from her high school chemistry class. She felt the pre-lab assignment was not helpful in preparing for the lab because it was "mostly mathematical equations or something...I could do the pre-lab and not read the lab." The pre-lab lecture helped explain the procedures, but not "why we're doing such things." Thus, she felt the pre-lab guide would give her a better understanding of the procedure, and "if you had any questions, you're going to have specific questions, not 'I don't understand steps 1 through 6!'". Lynda found that doing the experiment was helpful in writing the lab report, but that "the pre-lab assignment's not."

Lynda described her high school chemistry course as "a total joke." "We had very few labs," she said, and she often went to her mother, a research technician, for help. She expressed concern about her prior knowledge of chemistry because "we didn't have some of the things in my chemistry class." Lynda felt she learned chemistry best by taking notes in class and "hearing it and writing it and seeing examples." She enjoyed the labs, because "actually taking what we learn in lecture and doing something with it in lab" helped her understand the research process her mother did every day. However, she did not think that with "two different lab instructors, we get the same information or the same help" in lab.

"For people to want to do work, to want to be in class, to want to learn, is just different," she said when asked to compare college and high school. In assessing her performance, Lynda noted that when the

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quiz questions involved "like an application of the labs, I don't get it." Failing a quiz was the likely result if one did only the pre-lab assignment or just skimmed the experiment. Otherwise, she felt it was "generally easy to get along in the class." She concluded, "I just feel like I'm doing OK, but then I find out I'm not."

Conclusions

Concern about student success in science courses permeates all levels of the science education community. Student understanding of the scientific process has been the focus of much of the concern among those who teach introductory college chemistry courses. The Task Force on the General Chemistry Curriculum (Lloyd, 1994) has recommended increased emphasis on laboratory-centered instruction. The pre-laboratory guide employed in this study was an attempt to help students learn how to think about reading a chemistry lab manual and preparing to perform the experiments by directing their attention to specific elements of the scientific process. The task was also designed to guide students to connect their prior experience of chemistry and the lecture content with the lab concepts and processes.

The results of the student survey and the student interviews indicated some limited success in achieving this goal. The students were positive about their experience in the general chemistry course overall. Generally, students who used the pre-lab guide to prepare for lab felt better prepared to conduct the experiment and more confident of their ability to learn chemical concepts and processes in the lab. Students in the researcher's treatment group were more positive about their use of the steategy, although students in both treatment groups found it time-consuming. Nonetheless, the value students placed on this learning task is evident in comments during the interviews by two of the students in the control groups. Finding the traditional pre-lab assignment inadequate, these students "voted with their feet." They reported studying with students in the treatment groups and discussing the pre-lab guide as they prepared for general chemistry lab in an effort to enhance their understanding of the chemistry concepts and processes.

Some of the concerns expressed by the students may be common across different locations, as a result of large classes which require multiple lab sections and different lab instructors, and traditional laboratory curricula, which place little emphasis on the process of chemistry. One concern in this investigation involved differences in teaching by the two lab instructors. This may be related to the significant instructor effect found in the analysis of the survey data. In a study by Bennett (1993), the discussion section instructors were provided extensive support, to the extent that they did little planning or thinking about students' problems in learning chemistry. The current study may have gone to the opposite extreme, and failed to provide enough scaffolding to the adjunct, who was learning to use this pre-lab guide just as the students were. This lack of confidence on the adjunct's part may account for the anxiety of the students about the lab questions on the tests and quizzes, and the more negative attitudes evident among her lab sections in both the survey data and the interviews. The perceptions of the two instructors also differed somewhat. The adjunct reported meeting some student resistance to using the pre-lab guide. The

researcher observed that the labwork went exceptionally smoothly with her treatment group.

Thus, a major recommendation for practice would be that in implementing a new approach to chemistry lab instruction, the training provided to the instructors be strengthened. Many lab instructors have a natural ability for teaching students, others lack this talent. However, even the "natural" teacher can benefit from structured and on-going training in appropriate methods and effective techniques. Regular meetings of the lab instructors in this study might have enhanced the outcomes of this intervention by ensuring that the teachers were knowledgable about the concepts and processes of the lab experiments and summarized the information in a similar manner on the pre-lab guides.

Effective teaching behaviors, identified by Kline et al. (1992), might be addressed in such instructor training programs. Among these critical behaviors are providing rationales, using organizers, communicating expectations to students, adjusting instruction to an appropriate level, helping students become independent learners, monitoring learning, and providing feedback. Similar recommendations for effective strategy instruction have been made by Harris & Pressley (1991), among others. In this study, students' perceptions might have been improved by periodic repetition of the rationale for using the pre-lab guide and by more extensive monitoring and feedback from the researcher and the lab instructor about their use of the pre-lab guide.

Some of the suggestions made by the students about the pre-lab guide might be incorporated in the implementation of the pre-lab guide into the general chemistry lab curriculum. Requiring less detail in the pre-lab guide as the level of student competence rises might increase the productivity of the time students spend on the task. Tailoring the pre-lab guide to the experiment might also be of potential benefit. Therefore, a question similar to those on the pre-lab assignment could be added to direct students' attention to specific features of each experiment. Students would thus have the best of both approaches to preparing for general chemistry lab.

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Table 1

Interview Participants

Name	Major	Group	Instructor
Amber	Biology	Treatment	Researcher
Elena	Biology	Treatment	Researcher
Hannah	Engineering	Control	Researcher
Lynda	Biology	Control	Adjunct
Manisha	Chemistry	Control	Adjunct
Nadine	Biology	Treatment	Adjunct
Robin	Biology	Treatment	Adjunct
Shanel	Biology	Control	Researcher